# Costs and Returns to Oyster Aquaculture In the Chesapeake Bay

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Prepared by:

Robert Wieland
Main Street Economics

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# Executive Summary

As wild stocks of oysters in the Chesapeake Bay remain in a severely depleted state, alternative forms of commercial oyster production are being tested. In Virginia, the practice of culturing oysters in cages off-the bottom has expanding considerably over the past four years. Much of this production utilizes triploid *C. virginica* seed stock set on micro-cultch, though some growers also use diploid seed oysters. In Maryland, only a few entrepreneurs have adopted contained aquaculture systems and, among them, float aquaculture is more widely employed.

Both forms of contained aquaculture (cages off-bottom and floats) are examined in the study with respect to productivity and capital, labor, and material costs. At an assumed mortality rate of 33 percent, contained aquaculture is shown to remunerate the estimated costs and to leave a significant residual as returns to capital and management. Returns net of estimated costs ranged from 66 to 30 percent for off-bottom cages.

In addition to contained aquaculture methods, spat-on-shell on bottom has been used extensively as a production method for harvest bars, managed reserves and sanctuaries in Maryland. This method has historically utilized wild seed oysters from productive seed bars in Maryland's Chesapeake Bay. But more recent efforts have focused on disease-free hatchery-produced spat-on-shell. Using three years of harvest data from the managed reserves, the study shows that, so far, the net returns to this production method are highly negative. That is, costs exceed commercial benefits by a large margin.

While Virginia enjoys a history of private oyster aquaculture and the institutional framework to manage this industry, Maryland does not. The report discusses several obstacles that undermine investment in contained oyster aquaculture in Maryland. Chief among these are: poor property rights protections, lengthy regulatory processes (up to three years), and input supply bottlenecks. The objective of increasing commercial oyster production in Maryland's portion of the Bay would be served by addressing those constraints. The report provides a list of ways in which this might be done, including:

1. Improved access to bottom leases throughout both State and County waters (i.e., removing moratoria on bottom leases, mapping available bottom for leases and marketing them, limiting the time and money costs of acquiring leases, among others),
2. Development of a general permit for off-bottom cages, reducing the time and money costs of achieving regulatory compliance for that grow-out method,
3. Consideration of some judicious use of restoration funding for both private and public agency costs associated with oyster aquaculture permitting and water quality certification,
4. Development of crop insurance for aquacultural output with a particular focus on disease losses,
5. Undertaking greater extension and training in contained oyster aquaculture systems,

6. Ensuring an enabling environment for branding and marketing aquaculture product, and
7. Improving the enforcement of private oyster property rights by expanding policing and increasing the penalties for ignoring those rights.

# I. Introduction

In the continuing effort to restore the Chesapeake Bay oyster fishery, considerable investments have been made in oyster aquaculture. In Maryland's portion of the Bay, the bulk of this investment has been extended to what I will call "bottom culture". That is, spreading seed oysters on the bottom to grow to size. Virginia has used its restoration resources more broadly to aid both those who work "public oyster bottom" and those who hold private leases to oyster growing areas. In both States, some growers have invested their own funds to grow oysters in contained systems. These methods include various types of floats and cages off-bottom, among others.

This report discusses costs and returns to these various types of oyster aquaculture, using information gleaned from producers to generate enterprise budgets for two "contained" methods – floats and off-bottom cages. The spat-on-shell on bottom method is modeled using recent planting (disease-free hatchery produced oysters) and harvest data from Maryland's harvest reserves, reported by the Oyster Recovery Partnership (ORP). Product price data are from MD DNR Commercial Fisheries Statistics.

On bottom oyster culture has been practiced in various forms in both Maryland and Virginia for over 100 years. Contained aquaculture is a more recent innovation in the Bay, although variants of these methods have been practiced elsewhere in the United States since the 1970s[1]. Whereas traditional spat-on-shell production relied on naturally occurring seed oysters which were collected and moved to aquaculture sites for grow-out, both the spat-on-shell and contained oyster aquaculture described in this report are currently based on hatchery produced, disease-free oysters. This shift away from natural seed oysters is a function of both their relative scarcity and disease concerns.

The three methods addressed here have different cost characteristics which are discussed in the following section on enterprise budgets. These are developed from structured interviews with entrepreneurs who have produced oysters for market using the relevant technology. In Maryland, the two producers who cooperated were, by best available estimates, the entire active industry in Maryland's portion of the Chesapeake Bay at the time of the study. While there are more producers using contained aquaculture in Virginia than the two interviewed, it is unknown how many more. Contained aquaculture in the Chesapeake Bay is an emerging industry and, while the firms who cooperated for this study are thought to be representative with respect to technology and costs, it is less clear how representative they will be of longer term costs and technology as experience accrues and as innovation drives down costs.

Costs and returns are assumed to be an important consideration for private producers. However, in both Maryland and Virginia, there are economic and regulatory factors that may constrain adoption of a particular method and in the next section of the paper those factors are discussed in the context of institutional and regulatory issues. In a final

[1] National Research Council, 2004

section, opportunities and constraints are discussed in a more general framework and recommendations are made for more sustainable restoration of the commercial fishery.

# II. Enterprise Budgets for Three Aquaculture Methods

## *A. Off-bottom Cages:*

Off bottom cages have recently been adopted in Virginia by pioneering oyster aquaculturalists, primarily to grow-out triploid eastern oysters[2]. Production information was provided by two different firms, both working on the Rappahannock River in Virginia. Both firms had additional, vertically linked production operations, but both appeared to be earning a positive return from their oyster growing operations. Below, I describe the nursery and grow-out operation as generally practiced by these firms. Capital and operating and maintenance costs are estimates only, merging information from both operations when possible.

### 1. Equipment and Material Costs

Off-bottom cages employ seed oysters set on micro-cultch as their starting stock. The sampled aquaculture operations found it beneficial to buy smaller seed oysters and “nursery” them in upwellers until they become large enough to place in cages off the bottom.

In recent years, diploid seed oysters in the range of 2 to 4 mm have cost between $6 and $6.50 per thousand. Triploids cost between $7 and $7.50 per thousand. During the nursery processes and through grow-out, there is some mortality. This loss is estimated by the producers at between 30 and 40 percent of the starting population. In the cost estimates used below, we assume a 33 percent loss. Thus, if one wants to produce one million marketable oysters, they should start with about 1.5 million seed oysters at a cost of $11,250 for triploid and $9,750 for diploid oysters.

Growing new seed oysters to a size that can be placed in bags and cages requires a system that can keep predators at bay and deliver food in sufficient quantities for rapid growth. Both operations used a floating upweller to do this. These are basically floating docks with two rows of partially submerged tanks with screened bottoms that hold the seed oysters. Water is caused to flow up though the screen at the bottom of each tank by pushing water out of a central cavity in the upweller. This flow of water past the seed oysters creates a good environment for rapid growth. Floating upwellers cost anywhere from $3,500 to $7,500.

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[2] triploid oysters are spawned to be infertile. Because they do not invest energy in reproduction, they grow much faster than a regular “diploid” oyster.

As they grow, the seed oysters are screened and separated so that their growth is not limited by the volume of the tanks. Some producers separate growing seed oysters by growth rates, others separate them randomly until their final sort. As the oysters approach a size that can be placed in cages, they must be separated by size to ensure that those that are not large enough to stay in their grow-out container remain in the upweller. A shaker table is useful in this context and those cost between $4,000 and $8,500.

Growers use barriers of different mesh size to start the final grow-out in off-bottom cages. The cages are typically built of one inch wire mesh and range in size from 3' x 6' x 4" to 3' x 4' x 8". Because it is costly to keep seed oysters in the upweller and because of the nature of their growth with respect to space, growers want to get new oysters out into cages as soon as possible, generally before they are large enough to be contained by the one inch mesh of the cage. Some growers place new oysters in bags while others simply line their cages with a smaller mesh material.

In the 3' x 6' x 4" cages, 3000 or more new oysters might be placed in a single cage. These will have to be separated before they are ready for market, however, and by that final sort, the number will be reduced to about 1,500 oysters per cage. Cages cost around $85 for a single unit and $125 for a double-stacked unit[3]. One million oysters will require, ultimately, 667[4] cages for a material cost of between $41,625 and $56,610. Bags can cost another $6,630. Plastic liner material might cost $3,400 but bags are re-usable and it is not clear that the plastic liner can be re-used.

Cages off bottom are typically tied along a long line, creating rows that help to keep track of different cohorts of oysters. A boat with a power winch and gaff is required to place the cages and to retrieve them. A Carolina skiff or any similar small boat is adequate to this task[5] and the preference for placing the oysters in water that is only 3 to 10 feet deep makes a shallow draft also preferred. The mast and gaff cost in the range of $3,000 to $4,500. The boat and motor are assumed to be paid (off budget) in this analysis. Rope and gear for the long line system assuming one million marketable oysters will cost between $2,407 and $4,364.

A final piece of equipment that is useful for the final stages of sorting and cleaning oysters prior to sale is a sorting table and tumbler. While this final sorting and cleaning can be done by hand, the relative cost efficiency of labor versus capital tilts toward capital with larger throughput. A sorter that will handle a bushel of oysters in about one minute is about $8,000.

## 2. Labor and Energy Costs

[3] A double stacked unit can hold approximately twice the product of a single stacked unit
[4] A single rack cage will require 667 cages, a double rack system, half that many. The lower cost estimate is the double rack cage system, the higher cost is single rack cages.
[5] Larger operations are experimenting with shallow-draft vessels with greater carrying capacity.

There is wide variability in the amount of time that can be used to grow seed oysters to market size by way of off-bottom cages, but some handling and care is required. It is likely that closer care (as in more regularly separating and tumbling growing oysters) will facilitate faster growth up to a point and, in this sense, higher labor costs might generate higher returns from a larger or more rapidly grown product. But an estimate of this relationship is beyond the scope of the present study which will focus on reported average tending activities and average output. For the following labor estimate, a starting population of 1.5 million oysters is assumed and it is further assumed that this starting population will generate 1 million harvestable oysters.

Tending seed oysters in a floating upweller is estimated at 8 man hours every two weeks. This continues for the majority of the time that the seed oysters are in the upweller (i.e., up to three months). Sorting oysters, filling bags and placing cages is estimated to take 24 man hours per sixteen cages or, 1.5 man hours per cage. If cages are filled with approximately 3,000 oysters during their early grow-out then 500 man hours would be required over the three months that they are being gradually moved out of the upweller. As those oysters grow in their bags or lined cages, they will need to be separated at least once again for a final oyster count per cage of 1,500. This second sorting is not consistent such that a set of 8 cages is at once expanded to 16 cages, and most cages are probably sorted more than twice. However, for this (conservative) estimate of labor demand, we assume that each 3000 oyster cage is exchanged for two 1,500 oyster cages in one sort, implying another 750 man hour labor requirement over an entire compliment of oysters. Harvest then constitutes the final labor requirement and that is estimated at rate commensurate with the first two processes; another 1,000 man hours.

Total labor demand for growing out 1.5 million seed oysters or 1 million market oysters on the basis outlined above is estimated at 2,250 hours or 281 man days. Triploid oysters take 18 to 20 months to grow to market size, so this labor requirement is spread over a longer period than one year. Moreover, some of the jobs that make up this labor demand require at least two workers so this estimate should not be taken to imply that the labor requirement can be satisfied by one man working full time for a year.

The principal energy requirement for oyster aquaculture is electricity to run the upweller and sorting equipment. Assuming a ½ horsepower pump drawing 180 watts and a kilowatt hour charge of $0.145649, the electricity cost will be 2.62 cents per hour. If it runs continuously for three months, such a pump would consume $57.35 worth of electricity. If the pump draws 350 watts, it would consume about $111.57. These costs, even if twice as high as estimated, do not account a very large share of production costs.

## 3. Summary Cost Estimate

**Table 1** summarizes the costs discussed above. In using these costs to arrive at an estimated net return to oyster aquaculture, it is necessary to consider the length of time required for grow-out. In reality, oysters in any given cohort are reaching harvest size at different rates. However, since the curve for this is not known, it is simply assumed in this analysis that all the oysters come to market after a fixed time. For diploid oysters this time is assumed to be 24 months[6]. For triploids, it is assumed to be 18 months. By accounting this length of time, it is then a simple matter to factor the annualized equipment costs so as to generate a start-to-end cost for any given cohort.

Because the oysters are growing to market size (and, presumably being marketed) at some rate that varies around the single values suggested above, and because the labor cost is distributed over time, it is very difficult to predict the financial costs of the investment. At start-up, however, there will be material and equipment costs of between about $58,000 and $96,000. In the analysis, these costs are being allocated across years without respect to money costs of time.

**Table 1: Estimated Production Costs for 1 Million Oysters in Off-bottom Cages**

| Item | Cost | | Per Million Product |
|---|---|---|---|
| | | | |
| Triploid seed oysters (1.5 million) | 11,250 | -- | 11,250 |
| Diploid seed oysters (1.5 million) | 9,750 | -- | 9,750 |
| Labor (low: $8/hr * 2,250) | 18,000 | | 18,000 |
| Labor (high: $8/hr * 4,500) | 36,000 | | 36,000 |
| | | **Expected Life** | **Annualized Cost** |
| Bags & barriers (low) | 3,400 | 2 years | 1,700 |
| Bags & barriers (high) | 6,630 | 4 years | 1,657 |
| Lines, buoys, anchors (low) | 2,407 | 4 years | 602 |
| Lines, buoys, etc (high) | 4,364 | 4 years | 1,091 |
| Gaff & winch (low) | 3,000 | 5 years | 600 |
| Gaff & winch (high) | 4,500 | 5 years | 900 |
| Cages (low) | 41,625 | 6 years | 6,938 |
| Cages (high) | 56,610 | 6 years | 9,435 |
| Floating upweller (low) | 3,500 | 8 years | 438 |
| Floating upweller (high) | 7,500 | 8 years | 938 |
| Shaker table (low) | 4,000 | 10 years | 400 |
| Shaker table (high) | 8,500 | 10 years | 850 |
| Sorter/cleaner (low) | 0 | -- | 0 |
| Sorter/cleaner | 8,000 | 10 years | 800 |

**Table 1 (Source: Project Data, Chesapeake Bay Oyster Company Farm Planner)**

In the "per cohort" estimates that follow, although the focus is on a single cohort, production is assumed to be continuous. It is also assumed that there is some labor-capital trade-off, such that the high-end capital investments are more reasonably paired with the lower labor estimate and vice-versa. With those assumptions, the cost estimate for a single cohort of the two different seed stocks is as follows:

[6] More realistically, the length of time depends on the month the oysters are put in the water, as there are three months during the winter when the native oyster does not grow.

| | Costs |
|---|---|
| Low-end labor/high-end capital triploid | $52,757 |
| High-end labor/low-end capital triploid | $63,266 |
| Low-end labor/high-end capital diploid | $59,092 |
| High-end labor/ low-end capital diploid | $67,105 |

These estimates do not include capital carrying costs or maintenance costs (except in replacement) and, perhaps most importantly, they do not capture the cost of either a boat or a facility at which to dock a boat and maintain equipment and gear. But they do provide a straight-forward estimate of the principal labor, equipment and material costs of taking a cohort of one million oysters from seed to market. Labor costs are estimated at a low rate[7], but to the extent that the investors are providing some of this labor, they obtain additional income from the residual difference between costs and total returns. At these costs, a projected output of 2,500 bushels[8] with an assumed price of $35/bushel generates a net return of between $34,743 and $20,395. Especially at the higher end, such residuals provide returns to capital and management.

## *B. Floats*

Floats are another widespread system for oyster aquaculture. In Virginia, aquaculturalists have experimented with floats as part of the *C. Ariakensis* production trials[9] and in oyster production trials more generally[10]. In Maryland, several pioneering aquaculture firms are using floats for commercial oyster production. The following discussion of costs and production information is based on interviews with the managers of two such enterprises.

Floats hold growing oysters at the top of the water column where there is abundant food and anoxia is generally less of a problem. In Maryland, where bottom leases are less widespread and difficult to obtain, floats are an attractive alternative to either bottom culture or off-bottom cages. Floats are typically made of a 5” PVC pipe frame of various dimensions. The most common float size observed in the current research was 3’x 6’. A wire mesh container is attached to this frame and oysters are placed either directly in that container or in finer mesh bags as described below.

### 1. Equipment and Material Costs

Seed oysters set on micro-cultch are the principal starting stock in floating grow-out systems. Producers either spawn their own seed oysters or buy these from Virginia

[7] One of the enterprises used guest workers at this low rate and the other did not have an explicit labor cost because everything was done by the two partners.
[8] Note: The rate of 400 oysters to a bushel is used here. Producers used an estimate of 500 oysters per bushel but even given the larger size of Virginia bushels ( 7% larger than MD bushels) this does not map reasonably with either costs or price per oyster. Oysters produced by contained methods are smaller, deeper and not “clumpy” and this justifies using a higher rate than usually used for Virginia (350/bu) and Maryland (300/bu).
[9] Lipton, et al., 2006.
[10] Chesapeake Bay Foundation, 2005.

nurseries. Both firms traditionally use diploid oysters, though one had shifted to triploid stock in the current year due to diploid supply constraints. Seed oysters coming from the hatchery require additional growth before they can be placed in their grow-out containers and for this requirement one firm used a floating upweller and the other a dock-based down-welling system. Seed oyster costs are estimated at the same price as the off-bottom cages purchase price: $6 to $6.50 for diploids and $7 to $7.50 for triploid 2 – 4mm seed[11]. To the extent that MD producers have to drive to Virginia to get their seed oysters, there is some addition cost to them. However, such added costs are not likely to account for significant differences at the level of generality at which the present estimates are made.

The floating upweller costs remain between $3,500 and $7,500. The down-welling system was a lower cost in its purchase price, but its operating costs likely exceed those of the floating upweller due to higher labor and electricity costs. With both systems, tanks need to be cleaned and growing seed oysters separated. Growth was similar, for both diploid and triploid seed oysters and growers allowed up to 4 months for this, though some seed would be ready to put in containers as quickly as one month after starting them in the nursery.

As seed oysters grow, they are removed from their nursery and placed in smaller mesh bags. These are put in floats to grow. A bag of recently nurseried seed oysters might be packed as high as 20,000 to a single float. At market, however, the bag count will have dropped to 800 to 1,000 oysters per float. It is estimated by producers that any given oyster is probably sorted 6 to 8 times before market. Ultimately, perhaps 1,000 floats will be needed to bring 1 million seed oysters to market[12]. These are estimated to cost between $40 and $65 per float for a total cost of between $40,000 and $65,000. Bags or liners with different mesh sizes are needed and our estimate is that 500 of these are required before a sufficient portion of new stock can be placed in float containers without additional containment. At a nominal cost of $5.00 per bag or liner, this suggests an additional $2,500 in materials costs.

A shaker table or sorter facilitates the tending and partitioning of oysters in bags. A shaker table costs between $4,000 and $8,500, and a sorter is priced at $8,000. Floats do not require boats and winches for handling, but they do require workers who are willing to wade into the water to set and retrieve them. It is also possible to work floats from a boat but, among the two firms examined, they were rigged from the dock to a distant anchor on a mooring system. These were in 3 to 6 feet of water and were largely worked by hand and without a boat. In addition to pulling bags out to separate stock, floats need to be turned once a month to mitigate fouling and thereby improve the flow of water past the oysters.

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[11] Costs and returns to management from hatchery operations are assumed to be similar across these different institutional and market arrangements.

[12] This assumes a 2 year grow-out. Float requirements may be less with a one year grow-out as when faster growing oysters are sold and the floats are reused for slower growing stock. While this variable growth factor will influence two-year oysters similarly, it is likely that most oysters will have expanded in size to require lower oyster counts per bag; well before marketed floats can start to be reused.

## 2. Labor and Energy Costs

Labor is difficult to estimate for float aquaculture, based solely on the data obtained in this study. This uncertainty not withstanding, we can calculate from the number of treatments and reported labor estimates[13] an average time requirement per treatment. That is, if we take 50 bags of 20,000 seed oysters across six sorts to bags of 1,000 market oysters, about 2,550 treatments are implied. If we estimate 2 men, 4 days a week over a 20 week period, 1280 hours are implied. The implied per-float time then is about ½ hour – a not unreasonable estimate. Adding another 500 hours for harvest and 300 for cleaning and tending the upweller, generates an estimated labor requirement of 2,080 man hours for a cohort of 1 million oysters.

Electricity costs are similar to those discussed for the off-bottom cages budget (i.e., low), and are not significant in this analysis. The exception to this is the downweller system, which has significantly higher electricity costs due to the large number of pumps required to bring water to the tanks.

## 3. Summary Cost Estimate

The equipment, stock and labor costs discussed above are summarized in **Table 2**. As in the prior discussion of off-bottom cages, annualized costs are factored by the length of time required to obtain a final product so that a start-to-finish cost per million can be estimated. A mortality rate of 33 percent is assumed and the length of time is estimated to be 18 months for triploid oysters and 24 months for diploid oysters. Start up costs will be between $52,407 and $95,864. As in the previous example, these start-up costs are allocated over the useful life of the investments in **Table 2**.

Higher equipment costs are paired with lower labor costs and vice versa in these cost estimates. For a starting stock of 1.5 million seed oysters and a marketed product of 1 million oysters, the cost estimates are as follows:

| | **Cost** |
|---|---|
| Low-end labor/high-end capital triploid | $59,659 |
| High-end labor/low-end capital triploid | $62,628 |
| Low-end labor/high-end capital diploid | $68,748 |
| High-end labor/low-end capital diploid | $67,160 |

[13] Specifically, 4 people 4 days a week during the summer (24 weeks). N.B. This staffing handled many more than the hypothetical 1 million that we consider here and is factored accordingly (by .5) in the estimates.

**Table 2: Estimated Production Costs for 1 Million Oysters in Floats**

| Item | Cost | | Per Million Product |
|---|---|---|---|
| | | | |
| Triploid seed oysters (1.5 million) | 11,250 | -- | 11,250 |
| Diploid seed oysters (1.5 million) | 9,750 | -- | 9,750 |
| Labor (low: $8/hr * 2,080) | 16,640 | | 16,640 |
| Labor (high: $8/hr * 4,160) | 33,280 | | 33,280 |
| | | **Expected Life** | **Annualized Cost** |
| Bags & barriers (low) | 2,500 | 4 years | 625 |
| Bags & barriers (high) | 2,500 | 2 years | 1250 |
| Lines, buoys, anchors (low) | 2,407 | 4 years | 602 |
| Lines, buoys, etc (high) | 4,364 | 4 years | 1,091 |
| Floats (low) | 40,000 | 4 years | 10,000 |
| Floats (high) | 65,000 | 4 years | 16,250 |
| Floating upweller (low) | 3,500 | 8 years | 438 |
| Floating upweller (high) | 7,500 | 8 years | 938 |
| Shaker table (low) | 4,000 | 10 years | 400 |
| Shaker table (high) | 8,500 | 10 years | 850 |
| Sorter/cleaner (low) | 0 | -- | 0 |
| Sorter/cleaner | 8,000 | 10 years | 800 |

**Table 2 (Source: Project Data)**

Using the same estimate of 400 oysters per bushel used in the previous example, output of 2,500 bushels is projected. At $35/bushel this would generate net returns of between $27,841 and $18,752. Financial costs, unaccounted boat and facility costs and returns to management would need to be paid from this net.

## *C. Oysters on bottom, spat-on-shell*

Placing seed oysters on private and public oyster bottom for future harvests has been an important component of the Chesapeake Bay oyster fishery for many years. In Maryland, this has entailed dredging seed oysters from areas where they are abundant and taking them to grow out on public bottom where oysters are less abundant. In, Virginia, similar practices were employed by private operators who possessed bottom leases. The advent of Dermo and MSX, first in Virginia's waters[14] and later in Maryland's, reduced the economic sustainability of this practice for private operators who needed to make a positive net return.

Maryland, where oyster repletion is funded largely from the public budget, continued to use wild seed oysters to populate public oyster bottom higher in the Bay until 2004. Since then, a shortage of seed oysters and of shell substrate to maintain seed bars has limited

[14] See Santapietro & Shabman, and Lipton and Kirkley, 1994.,

the practice to near zero.[15] In its place, managers have begun to use hatchery-produced disease-free seed oysters, set on shell in a controlled environment to restore both public oyster bottom and new categories of oyster bottom called harvest reserves and sanctuaries.

In Maryland, the use of hatchery-produced seed oysters for on bottom planting is driven in part by "restoration" objectives; some of which are not remunerated in the marketplace. In particular, on bottom plantings are intended to provide environmental benefits and to maintain harvest practices (such as hand tonging) that are not particularly efficient. These objectives confound a simple cost-benefit analysis that considers only commercial returns to harvests. In Virginia an experiment is underway to encourage holders of oyster bottom leases to set and plant (hatchery disease-free) spat-on-shell for harvests for commercial profit. As this experiment is still being implemented, a confident appraisal of its economic feasibility is not yet possible. However, preliminary findings indicate that fast growing triploids harvested by dredge can provide a positive return to harvesters.[16]

Although Maryland's planting of diploid spat-on-shell is not expected to generate direct commercial benefits on oyster sanctuaries where the oysters and their progeny are not supposed to be harvested, planting hatchery disease-free seed on harvest reserves and harvest bars are both intended to generate commercial benefits for watermen. Although the program that has been instituted to generate these benefits is only about seven years old, several managed reserve sites have been opened for harvest, providing a preliminary record of the costs and returns to these efforts. **Table 3** reports the costs of preparing these sites and planting hatchery-produced disease-free oysters on them.

**Table 3: Production Costs for Spat-on-shell On Bottom**

| Planting Year | Managed Reserve | Shell Costs | Transport Costs | Seed Costs @$10k/mil. | Summed Production Costs |
|---|---|---|---|---|---|
| 2001 | Blunts | $48,792 | $12,590 | $150,000 | $211,382 |
| 2002 | Blunts | $147,222 | $5,500 | $182,000 | $334,722 |
| 2003 | Blunts | $131,812 | $9,000 | $359,000 | $499,812 |
| 2001 | Bolingbroke | $31,351 | $5,600 | $150,000 | $186,951 |
| 2002 | Bolingbroke | | $4,300 | $149,300 | $153,600 |
| 2003 | Bolingbroke | $88,706 | $9,000 | $412,000 | $509,706 |
| 2001 | Emory Hollow | | $5,600 | $50,000 | $55,600 |
| 2002 | Emory Hollow | | $2,500 | $6,530 | $9,030 |
| 2001 | Broadneck | | $4,550 | $52,000 | $56,550 |

**(Sources: Shell Planting volumes and costs, DNR Seed and Shell Reports and ACOE data. Seed oysters and costs, ORP data)**

[15] See Herberich, 2006 for a discussion of the economics of this practice
[16] Melissa Southworth and others, NOAA Chesapeake Bay Office Summer 2007 Quarterly Review of Non-Native Oyster Research

These costs do not capture any overhead or administrative costs. Most importantly, they do not capture the costs of harvesting the oysters. In the descriptions of cage and float oyster aquaculture, the enterprise budgets assumed an f.o.b. product price, at the dock or at the producer's gate. Because in Maryland various public-sector payers fund the production process, the private costs of harvesters to retrieve the oysters from the bottom and bring them to the dock is sometimes obscured; but it is none-the-less a cost of bringing the oysters to market.

An earlier study of operating costs in Maryland's public oyster fishery[17] estimated the low-end daily boat and fuel costs for shaft tongers to be $31 and $24, respectively. These costs are applied to sites that were harvested by shaft tongers. However, Blunts was harvested primarily by divers and their low-end average costs were somewhat higher at $51/day for the boat and equipment and $27/day for fuel. Combining those costs with bar and year-specific average time spent harvesting (factored at $8/hour[18]), **Table 4** reports production and harvest costs alongside dockside values. The market price of the oysters harvested from these bars is simply estimated at $30/bushel[19]. At that price, costs range from 1.6 to 1000 times the oysters' sale value.

**Table 4: Production and Harvest Costs and Commercial Returns**

| Planting Year | Managed Reserve | Production Costs | Harvest Costs | Harvest Returns | Total Costs/Returns |
|---|---|---|---|---|---|
| 2001 | Blunts | $211,382 | $8,588 | $46,719 | 4.71 |
| 2002 | Blunts | $334,722 | $7,967 | $44,790 | 7.65 |
| 2003 | Blunts | $499,812 | $7,654 | $38,490 | 13.18 |
| 2001 | Bolingbroke | $186,951 | $1,960 | $9,585 | 19.71 |
| 2002 | Bolingbroke | $153,600 | $9,295 | $32,078 | 5.08 |
| 2003 | Bolingbroke | $509,706 | $946 | $510 | 1001.28 |
| 2001 | Emory Hollow | $55,600 | $7,662 | $29,175 | 2.17 |
| 2002 | Emory Hollow | $9,030 | $897 | $615 | 16.14 |
| 2001 | Broadneck | $56,550 | $31,385 | $53,730 | 1.64 |

**Table 3 (Source: DNR, ORP and Wieland, 2006)**

The spat-on-shell on bottom method has the advantage of requiring relatively less labor than the contained systems and of focusing this labor requirement in a relatively short period. Its drawback is that not a very large portion of what is originally put out is ever harvested. During the same growth phase that cultured seed oysters are being carefully nurseried under the two contained aquaculture approaches, they are washed overboard

[17] Wieland, 2006
[18] While self-employed harvesters might expect higher returns to their labor than $8/hour, this figure is used to remain consistent with contained aquaculture labor costs.
[19] The rationale for a lower priced bushel of on-bottom oysters is that due to their characteristics there are fewer oysters in a bushel (variously estimated at 300 to 350 oysters per bushel) relative to a bushel of aquacultured oysters (estimated at 400 to the bushel). These different prices are reflected in the market.

and deposited into an unprotected environment in the spat-on shell on bottom method. There is generally a large (50+) mortality soon after planting and then a more gradual rate of mortality over the three to five years that the oysters are left on the bottom. In addition to this mortality, at harvest only some portion of the remaining oysters is actually retrieved from the bottom. Divers tend to clean a bar more completely and shaft tongs leave more oysters behind[20].

The spat-on-shell model as practiced in Maryland has been adaptive, changing as resources have expanded and as new techniques have come on line. The numbers reported in Tables 3 and 4 have used the costs and production efficiencies that currently obtain and extrapolated these back to prior years when higher costs and lower efficiencies were the rule. Continued efficiency gains in setting and transporting seed oysters are possible, as are more cost effective means for preparing the bottom to receive seed oysters. But such gains will be muted by the large mortalities and inefficient harvest methods associated with the Maryland's oyster restoration model, at least with respect to commercial cost-recovery.

## *D. Relative Costs and Returns*

By any basic financial measure, the modeled returns of contained aquaculture exceed those estimated for on-bottom aquaculture by a large margin. However, as these are different processes subject to different institutional arrangements, costs are treated differently between the two sets and it is meaningful to consider these differences when comparing net returns. Moreover, because contained oyster aquaculture as practiced in the Chesapeake Bay is a technology still in its infancy, there is limited scope for using historical financial information for determining optimal production volumes at given levels of investment.

By choosing an end product of one million oysters for contained aquacultural production, the modeled estimate does not necessarily capture the efficiency price of production for contained aquaculture. It is likely, in fact, that such capital investments as upwellers, shaker tables and sorters are under-utilized with a one million oyster cohort. On the other hand, docks and on-shore facilities were not accounted in the estimate of contained aquaculture costs and these could be substantial. Some of the returns, net of the costs accounted in model would, in a more complete analysis, be applied to an annualized cost for such facilities.

The estimate of contained aquaculture also did not account boat costs, except for the gaff and winch as described. A boat was not essential for float aquaculture, but helpful. A boat was necessary for off-bottom cages, but at the modeled level of production, the time employment of a boat is not likely to be a major cost factor (as shown, below).

[20] See Lenihan 2004.

With respect to on-bottom aquaculture targeting shaft tong or diving harvest methods, a boat is an essential part of the harvest process. Moreover, because of the common property aspect of oysters in Maryland's managed reserves, harvest efficiency on any given site will range from high (at the start of the season) to low (as the site is worked-out). The method used for estimating harvesting costs on the four managed reserves used total effort, which captured this declining harvest productivity as a simple average. Clearly, with more efficient gear, these harvest costs could be reduced. But that is not the practice currently engaged.

With respect to production costs for on-bottom oysters, it is not clear that the full costs of production are captured in our use of a fixed price of $10,000 per million spat-on-shell oysters[21]. Moreover, that cost estimate does not capture major administrative, monitoring and management costs associated with the managed reserves. These costs are likely substantial, and the current methodology, although new and evolving, is not subject to competitive pressures. These factors add to the difficulty of pricing those aspects of on-bottom production.

Bearing these caveats in mind, we can consider several alternative scenarios for both methods, using the cost factors described in the previous subsections. **Table 5** examines the costs of producing a larger cohort of oysters with off-bottom cages, using fixed equipment costs (e.g., one upweller, one shaker and one sorter). All other costs are assumed to increase by the same factor as the increase of the cohort so that to produce four times as many oysters requires four times as much labor, cages, starting stock, etc. As expected, holding some of the capital costs constant leads to not only higher returns but higher rates of return for all of the four starting stock/labor estimate scenarios.

**Table 5: Off-Bottom Cages Estimated Returns from Larger Cohorts**

| | Two Million Cohort | | Four Million Cohort | |
|---|---|---|---|---|
| | Cost | Net Return | Cost | Net Return |
| Triploid | | | | |
| low-end labor/high end capital | $99,607 | $75,393 | $195,332 | $154,668 |
| high-end labor/low-end capital | $123,924 | $51,076 | $246,592 | $103,408 |
| Diploid | | | | |
| low-end labor/high end capital | $110,309 | $64,691 | $215,443 | $134,557 |
| high-end labor/low-end capital | $130,732 | $44,268 | $259,789 | $90,211 |

**Table 5** maintains the mortality expectation of one third the starting stock. As calculated, total costs are not very sensitive to higher mortality factors, because mortality enters only as a need to start with a greater number of spat in order to ultimately fill an expected number of cages. Obviously, multiplying variable costs by factors greater than one increases total costs. Returns, however, increase faster. What is not known is where the practical limit is for annual throughput for the nursery and other equipment. Higher

[21] Horn Point Hatchery is both a production facility and a research facility and allocation of costs across these different uses is difficult.

levels of throughput than 1 million are probable for commercial operations, but nursery equipment will be a likely bottleneck at some (unknown) point.

The net returns from **Table 5** require one and one half and two years, respectively, for triploid and diploid starting stock. As noted, those estimates do not include costs such as land-based facilities and boats. A rough estimation of boat costs can be generated by factoring the number of boat-days required to move cages by an estimated boat-day cost. In the production scenario described for off-bottom cages, the total number of placements and retrievals for cages bearing the one million oysters is 1,665. If a boat can place and retrieve 25 cages per day, using the same workboat and fuel cost used for shaft tongers, 33 boat days at a cost of $55/day gives a total boat cost of $1,832 per one million oysters. This number can be factored by the number of oysters produced, such that 2 million oysters require $3,663 in boat costs and 4 million oysters imply $7,326.

For off-bottom cages at higher levels of throughput, there is clearly significant scope for paying facility, capital and management costs. Similar returns are generated by higher production volumes using floats (not shown). Given the negative estimated returns to on-bottom aquaculture, it may be more useful to ask, what would need to change to bring those negative returns positive?

Hatchery produced disease-free spat-on-shell is the largest visible portion of production costs for on-bottom aquaculture. Because of the large volume of material that is used for spat-on-shell, it does not seem likely that those production costs can be significantly reduced. However, potentially larger production costs are mortality and unharvested oysters; which are only indirectly visible in the cost estimate. If triploid oysters were used for on-bottom aquaculture, an additional year of mortality could be avoided and a larger stock would be available for harvest. Similarly, if dredges were used to harvest those oysters, a larger share of the available stock could be brought to market. The gains from both of these practices could conceivably be great enough to generate positive returns for on-bottom aquaculture.

Alternatively, perhaps commercial returns are the incorrect metric for evaluating these alternatives. If external benefits (i.e., environmental benefits or the social utility generated by having men using tongs to harvest oysters) are included in the analysis, perhaps these would favor on-bottom aquaculture. Evaluating those possibilities is beyond the scope of the present paper.

# III. Institutional and Regulatory issues

## *A. Virginia*

Virginia has had a private oyster harvest (production from leased bottom) in its portion of the Chesapeake Bay for over 100 years. In 1892, Virginia's Bay bottom was surveyed to delineate public oyster bottom from "barren bottom", where oysters were not generally found.  Oyster bottom leases were restricted to these barren areas.  Private leaseholders were permitted to collect naturally occurring seed oysters and place them on their lease for grow- out.  Within eight years of Virginia's delineation of oyster bottom, private leaseholders produced a larger harvest than did watermen working the public oyster bars[22].  This long history of productive private leaseholds was broken in the mid-1960s with the onset of oyster disease.  Harvests declined by half between the 1966 and 1967 seasons.  As the returns to buying and planting wild seed oysters became less certain, leaseholders did it less.  In the 2004 season, harvests from private leases dropped to an historic low (3,794 bu) that was 0.3 percent of the 1966 harvest.

Efforts have been on-going in Virginia to encourage private leaseholders to try again to produce oysters on private leaseholds.  With the start of the Virginia Seafood Council's (VSC) *Crassostrea ariakensis* trials in 2003, leaseholders were recruited to grow these triploid oysters in floats, cages and bags.  Through that process, growers were introduced to triploid growing stock and many were impressed with the performance of triploid *C. virginica*.  The fact that an institutional structure was already in place for such production doubtless helped to facilitate those efforts.  As the various methods and stock approaches have been tested, Virginia's regulatory framework has adjusted to ensure that it remains practical for leaseholders to employ these innovations.  In more recent developments, Virginia has instituted a program to off-set growers' costs of buying oyster larvae and setting it remotely (at the growers' location).  This program has only been in place for two years and results are not yet known.

An investor seeking an oyster aquaculture lease in Virginia must find bottom that is not already leased, does not fall within either Baylor grounds (public bottom) or the area required for navigation projects, and is not subject to claim by riparian owners.  On identifying such bottom, the applicant then must make application in duplicate to the Virginia Marine Resources Commission and pay a $25 application fee.  The application has to be published in a local newspaper for four consecutive weeks, giving interested parties from the public a chance to respond.  Depending on the public response, VMRC will then survey the lease for assignment.  The applicant must pay a fixed charge ($510.00) for this survey along with a plat charge ($75.00), a recording fee ($12.00), an assignment fee ($1.50) and the rental charge ($1.50/acre).  Apart from the $1.50/acre rental fee, these are one-time costs for a ten year lease.  However, at the end of this term, the leaseholder may be able to continue his lease another 10 years by making written application to VMRC.

Leases must be marked on their corners and along their boundaries at 150 foot intervals.  In keeping with changing technology, Virginia has adopted regulations specifying conditions upon which bottom structures (cages) can be used to contain oysters.  The Norfolk Army Corps of Engineers, who hold regulatory authority over structures in the water column has instituted a general permit allowing such bottom structures.

[22] Santopietro and others, undated.

## B. Maryland

Maryland has taken a quite different approach to regulating oyster aquaculture. Although a delineation of natural oyster bars in Maryland's portion of the Chesapeake Bay was undertaken early in the 20th century, the government there was not as successful as Virginia in using this delineation to enable private aquaculture. A five acre limit on leases, combined with a policy of reversing lease agreements if three witnesses asserted that oysters had been harvested from the site (i.e., expanding the earlier delineation of natural oyster bars) served to undermine incentives to acquire leased bottom in Maryland. Moreover, since many Maryland watermen did not accept the idea of private rights in oyster production, it was very difficult to enforce those rights.

Still, in 1974, there were 9,903 acres under lease in Maryland according to MD DNR statistics. The reported harvest from those leaseholds in the 1974 -'75 season was 56,648 bushels. This private production supplied about 2.21% of Maryland's total oyster harvest in that year. Beside the aforementioned constraints, supply of seed oysters for Maryland leases was limited by demand for seed oysters from Maryland's public fishery and restrictions on trade in seed oysters from Virginia. These limitations became increasingly binding over the 1980s and 1990s. By the 1990-'91 season, privately produced oysters were only 2,716 bushels, or 0.55% of total harvests. DNR statistics do not report any harvest from leased bottom in Maryland since the 2000-'01 season[23].

Traditional leased bottom oyster aquaculture in Maryland used the same methods employed by Virginia aquaculturalists in which seed oysters are spread over an appropriate substrate to be harvested when they reach market size. The lack of consistent shell and seed oyster access, combined with patchy prospects for survival to market has limited private investment in this method over the past several decades. More recently, aquaculturalists in Maryland have started to employ innovative production techniques; particularly float aquaculture which, as discussed above, appears to have some potential for generating positive returns. However, the economic opportunity represented by this shift in method has not yet generated more than marginal gains in the regulation of the industry. And, as discussed below, these alternative methods are charged higher rental rates than traditional leased bottom.

Float aquaculture has several characteristics to recommend it, such as rapid growth and good survival. But an even more compelling factor for its application is that it obviates the need for a bottom lease, which can be difficult to get if you do not already have one[24]. Instead of a bottom lease, float aquaculture as currently practiced in Maryland is allowed under a water column lease – as long as the project also satisfies a number of other conditions. As described below, the regulatory requirements for such leases create large costs for both the investor and the agencies responsible for permitting this practice.

[23] The author is aware of production from float aquaculture during this period, so it can be assumed the DNR data does not capture all private production.
[24] New leases are prohibited in Kent, Queen Anne's, Talbot, Dorchester and Somerset Counties.

An applicant for a water column lease first needs to have some riparian rights[25] at the site where the floats will be set. With that, the applicant then must apply for an aquaculture permit with MD DNR and file a joint federal/state tidal wetland permit application with Maryland Department of the Environment (MDE). The latter requires five copies with extensive documentation of the project and is circulated among the relevant agencies by MDE. The applicant will also have to obtain requisite County Planning and Zoning permits and to participate in public review of the project. Final approval of the wetlands permit requires the water quality certification. This latter process requires extensive water testing and takes between 18 months and 3 years to complete. There is no charge for filing the necessary applications for a water column lease, but, if awarded, these carry an annual fee of $80/acre. Additional one-time fees for the license can range from $250 to $1,000, depending on the size of the project. MDE bears the costs of water quality sampling and MD DNR will pay the publication charges for advertising a lease proposal.

The application fee for a bottom lease is $300. There is an additional $5 recording fee if the lease is granted and annual rental payments are $3.50 per acre. However, these rental payments are generally abated under current conditions. Thus, regulatory costs are a very mixed bag, with bottom lease permitting costs being somewhat less than Virginia's, but with continuing charges for a water-column lease being much higher than charges for bottom leases. Moreover, the time required to satisfy all of the permitting and licensing requirements in Maryland is considerably longer than Virginia.

While efforts are being made to expedite this permitting system, gaining approval for float aquaculture is currently a time-consuming and difficult process. It is also costly for the agencies, which must bear many of the costs of review and, in the case of water quality assurance, the costs of sampling and testing water around the lease. While the goals of the regulations are quite defensible (i.e., avoiding public harm with respect to navigation or the environment, protecting public health, etc.), alternative mechanisms for achieving them are not difficult to imagine. Most importantly, general permits of the type used in Virginia could greatly ease the time costs of permitting standard aquaculture operations. Water quality mapping in Maryland lags behind water quality mapping in Virginia in large part because Virginia has had a leased bottom program for one hundred years. In this regard, Maryland should be investing in remedial water quality mapping.

# IV. Summary and Conclusions

## *A. Summary*

Costing the operations of an enterprise, short of a time-motion study, requires many generalizations about capital, material and labor requirements. The present study is no

[25] Technically, one does not need riparian rights for a water column lease, but security and access issues make such rights practically necessary.

exception and, while material and labor costs have been assigned in a transparent manner, issue can doubtless be taken with the reported measurements and analysis. The investor putting his own capital at risk in one or the other of these enterprises would be well advised to do further research. On the other hand, the processes described above are explicit and the time and material costs that they entail track as expected with recent changes in the industry.

Virginia's private lease production follows a downward path from 1966 to the present because the primary method being employed – spat-on-shell on bottom – was not bringing a positive return to the investors. Whether this lack of return derived from scarce seed stock or too low rates of survival is a question that is being addressed by recent programs that encourage growers to invest in hatchery-produced (or, remotely set) disease-free seed. The growers will provide an answer to this question by either continuing or dropping their investments in spat-on-shell on the bottom, once the subsidy runs out.

With the decline of spat-on-shell production in Virginia, innovators have experimented with contained grow-out systems; first with floats and, more recently, with cages off-bottom. Although there is not yet much history, it appears that entrepreneurs are investing more in such systems. A recent report (VIMS, 2007) shows seed oyster sales from hatcheries doubling from 2005 (20.4 million) to 2007 (41.2 million[26]). In that same report, oysters sold by aquaculturalists are shown to have risen at an even faster rate over the same period. While the increase in seed oysters sold can be attributed to aquaculturalists using a contained method, it is less clear where the additional market oysters from aquaculturalists are coming from. Those figures may include an increase in spat-on-shell production.

Michael Congrove (VIMS, unpublished), has developed a spat-on-shell calculator based on Virginia data that predicts that, at setting rates of 10 percent, survival rates of 12.5 percent and harvest rates of 75 percent, a private return of 35 percent and better is possible. That rate compares favorably with the losses reported in **Table 4**. But it does not rise to the levels predicted for triploid stock in off-bottom cages.

Given the considerable range in costs for both off-bottom cages and floats, the differences in returns generated by this analysis should not be taken as predicting that the returns to floats will always be less than the returns to off bottom cages. Although as already noted, in Virginia, where producers have had a choice, they seem to have shifted to cages off bottom. In Maryland, where bottom leases are more difficult to obtain, and where no general permit is in place for off-bottom cages, floats may fill a niche for investors who want to grow oysters under a contained system and who have a dock, but not a bottom lease. It is not clear how large a niche that is. With respect to incentives, investors will need to pay over 22 times the bottom lease rent for a water column lease.

[26] 2007 is an estimate.

## B. Associated Issues

The effect of State policies on oyster aquaculture in Maryland was addressed in Wieland, 2007. Publicly-funded oyster repletion over the longer term and harvest-oriented oyster restoration more recently have both undermined investors' incentives to pay production costs other than those required to harvest oysters from seeded bars. If we compare the costs of harvesting oysters from sites that have been seeded, ignoring the costs of preparing and seeding them, the returns are clearly much better than those obtainable with either of the contained aquaculture methods. But is it dangerous to ignore the costs of restoring bars for harvest, because payment of those from the public purse may not be sustainable as the subsidy wears on and donor fatigue sets in.

In Virginia, oyster policies and resources have been directed largely toward reducing producers' costs at the margin. Recent programs subsidizing larvae and setting equipment target up-front costs that may serve as barriers to adoption. Depending on whether the production processes that are being encouraged are remunerative or not, some demonstration effect and consequent production benefit might be anticipated, after the subsidy funding runs out. In this, Virginia has had the benefit of a long history of private production to support its approach. This is missing in Maryland.

Adoption of innovative oyster aquaculture is also constrained by the structure of the harvest industry. Especially in Maryland, watermen have worked other fisheries during the spring and summer, returning to the oyster fishery in the late fall and winter. Contained aquaculture systems carry significant labor requirements in the spring and summer. While it is conceivable that a waterman might continue to work the summer crab fishery while growing oysters in a contained system, he will need to take some time out for tending seed oysters and floats or cages. It is likely that his time in summer will carry a higher opportunity cost than his time in winter. Therefore, for widespread adoption, returns to oyster aquaculture in Maryland's harvest industry would need to be competitive with returns to working these other fisheries.

In a 2002 survey of Maryland oyster bottom leaseholders (Webster and others 2004), when presented with a list of factors that might improve their interest in using leases more intensively, respondents rated the following as "extremely important" or "very important": Obtaining native disease-tolerant oysters (92.5%); access to shell (76%), access to natural seed oysters (73%), access to hatchery seed oysters (65%), access to a state-supported seed program (61%) and protection from theft (60%)[27]. In a question about water column leases, 51 percent of respondents said that they would be interested in obtaining one.

The respondents in the leaseholders' survey – people who have bottom leases in Maryland – are a much smaller group than watermen who have traditionally worked the

[27] These percentages only include the sets of respondents who answered the questions.

public fishery[28]. However, there is some overlap between these two groups and, as the public fishery shrinks, the relative importance of private aquaculturalists will likely grow. The responses indicate a continuing interest in aquaculture among growers, though the fact that not many of them have followed that interest with investments indicates that obstacles remain.

Disease tolerance has been a focus of oyster research in the Chesapeake Bay, but to date no conclusively resistant, successful strain of the native oyster has been developed. With respect to access to shell and seed oysters, availability of both these has declined over the interim from 2002 to present[29]. Protection from theft is only relevant to the extent that growers have something to be stolen, but Maryland Natural Resources Police have been operating with fewer field resources over the past 5 years[30]. As discussed above, water column leases are available, but at some cost in time and money. Growers' interests, by these measures, have largely not been served.

In Maryland, the bulk of oyster research and restoration efforts have focused on the public fishery, using spat-on-shell on the bottom. Contained aquaculture has not received in Maryland the level of support that it has in Virginia. Lipton (2007), looking at similar oyster aquaculture systems concludes that increased oyster production in the Bay at levels pursued under the Non-native oyster EIS will not be achieved solely through contained aquaculture. While this is likely, with respect to the more limited goal of increasing oyster production in a sustainable manner, the contained oyster aquaculture systems reviewed here seem a much better bet than spat-on-shell on bottom.

To see this, consider the following experiment. The $454,000[31] used for spat on shell bottom culture on the managed reserves in 2001 could have funded 8.6 contained aquaculture projects (one million cohort triploid stock in off-bottom cages). If each of those projects was successful, instead of generating a harvest 2,850 bushels of oysters from the managed reserves in the 2005 season, those funds would have generated as many as 43,000 bushels of oysters, assuming a second rotation of contained oyster culture.[32] If that same amount of money were used to fund 7.7 diploid aquaculture projects as outlined in the text, it would have generated one and a half rotations, or the equivalent of 28,800 bushels of oysters. And, in either case, the benefit of contained over on-bottom aquaculture is that, at the end of any given rotation, there are sufficient returns to keep going without constant infusions of external funds.

Of course, on bottom aquaculture on the managed reserves is not intended to be an efficient way of delivering commercial product. Rather, it is a way of providing harvestable stock for shaft tongers and divers. It also is promoted as a way of generating

[28] In recent times, leaseholders actually may outnumber the watermen working the fishery in any given year but the majority of those leases are not being actively worked and the point stands that, watermen who would work the fishery if there was any resource to capture far outnumber aquaculturalists.
[29] MD DNR Seed and Shell Report(s) 2002 - 2006
[30] Maryland State Budget, various years.
[31] This figure does not include expenses associated with Broad Neck managed reserve which was planted in 2001 but not harvested until the 2006 harvest season.
[32] This assumes that the returns from the first cohort (at 1.5 years) is reinvested to grow a second cohort.

environmental benefits from having oysters in the water. Clearly, triploid seed stock in contained aquaculture systems would not generate any recruitment effects. And it is not likely that all of the habitat benefits attributed to oyster bars on the bottom are as great if the oysters are contained in floats or cages. However, the difference in environmental benefits between these two approaches would need to be very great to justify spat-on-shell bottom culture as estimated here. This then begs the question of how it could be optimal to remove those oysters by harvest if the environmental benefits that they generate when they are small and growing are that great.

## *C. Conclusions and Recommendations*

Given the information presented on costs and returns to contained oyster aquaculture and spat-on-shell on bottom culture, these conclusions follow:

1. The enterprise budgets for contained oyster aquaculture indicate that investments in such systems can be remunerative. Recent market performance in Virginia supports this finding.

2. In Maryland, both regulatory and institutional constraints conspire to reduce incentives to invest in contained oyster aquaculture. The difficulty in obtaining leases, in meeting other regulatory requirements, and in ensuring property rights all increase the effective costs of oyster aquaculture.

3. The financial losses implied by current costs and returns to spat-on-shell on bottom in Maryland translate into a consumptive use of oyster restoration resources and not long term investments. While there is some indication that triploid spat-on-shell on bottom in Virginia is remunerative, the study has not been completed. Diploid spat-on-shell as practiced in Maryland is not commercially remunerative.

4. There is little public sector support for experiments in contained oyster aquaculture, particularly in Maryland. Such support could help to remove barriers, encourage innovations, and increase private investment in sustainable oyster production in the Chesapeake Bay.

Given those conclusions, a shift in the use of restoration resources in Maryland away from “put-and-take” schemes and toward more sustainable forms of oyster production and restoration is recommended. Clearly, restoration goals would be better served if restored oyster populations were left to grow instead of being harvested. Moreover, the use of restoration resources for producing oysters to harvest undermines the argument that such restoration carries other than short-term benefits for the fishery.

With respect to the production and harvests of oysters, contained oyster aquaculture is a much better near-term prospect than spat-on-shell on the bottom as a substitute for harvests from the public fishery. Restoration resources that target harvests of oysters would therefore be better applied toward creating an enabling environment for contained oyster aquaculture investment. A short list of recommendations for achieving increased investment in oyster aquaculture would include:

1. Improved access to bottom leases throughout both State and County waters (i.e., removing moratoria on bottom leases, mapping available bottom for leases and marketing them, limiting the time and money costs of acquiring leases, among others),
2. Development of a general permit for off-bottom cages, reducing the time and money costs of achieving regulatory compliance for that grow-out method,
3. Consideration of some judicious use of restoration funding for both private and public agency costs associated with oyster aquaculture permitting and water quality certification,
4. Development of crop insurance for aquacultural output with a particular focus on disease losses,
5. Undertaking greater extension and training in contained oyster aquaculture systems,
6. Ensuring an enabling environment for branding and marketing aquaculture product, and
7. Improving the enforcement of private oyster property rights by expanding policing and increasing the penalties for ignoring those rights.

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